

11/09/99
jc639 U.S. PTO

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

REQUEST FOR FILING APPLICATION

Under Rule 53(a), (b) & (f)

(No Filing Fee or Oath/Declaration)
(Do NOT use for Provisional or PCT Applications)
Use for Design or Utility Applications

jc511 U.S. PTO
09/436360
11/09/99
PATENT
APPLICATION

Page 1 of 2

RULE 53(f) NO DECLARATION

Assistant Commissioner of Patents
and Trademarks
Washington, DC 20231

Atty. Dkt.

PM 244889

M#

98-31-SE-REG

Client Ref

Date:

11/9/99

Sir:

1. This is a Request for filing a new Patent Application(☐ Design ☒ Utility) entitled:

2. (Complete) Title:

SYNTHESIS OF ENERGETIC THERMOPLASTIC ELASTOMERS CONTAINING
BOTH POLYOXIRANE AND POLYOXETANE BLOCKS

without a filing fee or Oath/Declaration but for which is enclosed the following:

3. ☒ Abstract 1 page(s).

4. 30 Pages of Specification (only spec. and claims); 5. ☐ Specification in non-English language

6. 40 Numbered claim(s); and

7. ☒ 2 sheet(s) per set; ☒ 1 set informal; 8. ☐ formal of size: ☒ A4 ☐ 11"

Drawings:

9. **DOMESTIC/INTERNATIONAL** priority is claimed under 35 USC 119(e)/120/365(c) based on the following provisional, nonprovisional and/or PCT international application(s):

Application No.	Filing Date	Application No.	Filing Date
(1) 60/108,458	November 12, 1998	(2)	
(3)		(4)	
(5)		(6)	

10. **FOREIGN** priority is claimed under 35 USC 119(a)-(d)/365(b) based on filing in

Application No.	Filing Date	Application No.	Filing Date
(1)		(2)	
(3)		(4)	
(5)		(6)	

11. (No.) Certified copy (copies): ☐ attached; ☐ previously filed (date)
in U.S. Application No. / filed on

12. ☐ This is a reissue of Patent No.

13. ☐ See top first page re prior Provisional, National, International application(s) (X box only if info is there and do not complete corresponding item 14 or 15.)

14. ☐ **Amend the specification** by inserting before the first line -- This is a ☐ Continuation-in-Part
☐ Divisional ☐ Continuation ☐ Substitute Application (MPEP 201.09) of:

14(a) ☐ National Appln. No. / filed -- (M#)

14(b) ☐ International Appln. No. PCT/ filed

15. ☐ **Amend the specification** by inserting before the first line: --This application
claims the benefit of U.S. Provisional Application No. 60/ , filed --

16. Extension to date: ☐ concurrently filed ☐ not needed ☐ previously filed

17. ☒ Prior application is assigned to CORDANT TECHNOLOGIES INC.

by Assignment recorded January 19, 1999 Reel 9706 Frame 0015

18. ☐ Attached:

19. This application is made by the following named inventor(s) (Double check instructions for accuracy.):

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20. NOTE: FOR ADDITIONAL INVENTORS, check box ☐ and attach sheet with same information regarding additional inventors.

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NOTE: File in duplicate with 2 post card receipts (PAT-103) & attachments

APPLICATION UNDER UNITED STATES PATENT LAWS

Invention: SYNTHESIS OF ENERGETIC THERMOPLASTIC ELASTOMERS
CONTAINING BOTH POLYOXIRANE AND POLYOXETANE BLOCKS
Inventor(s): Andrew J. SANDERSON, Wayne EDWARDS, Louis F. CANNIZZO, Robert
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This is a:

- ☐ Provisional Application
- ☒ Regular Utility Application
- ☐ Continuing Application
- ☐ PCT National Phase Application
- ☐ Design Application
- ☐ Reissue Application
- ☐ Plant Application
- ☐ Substitute Specification
Sub. Spec. filed _____
in App. No. _____ / _____
- ☐ Marked Up Specification re
Sub. Spec. filed _____
in App. No. _____ / _____

SPECIFICATION

SYNTHESIS OF ENERGETIC THERMOPLASTIC ELASTOMERS CONTAINING BOTH POLYOXIRANE AND POLYOXETANE BLOCKS

5 Priority is claimed on United States Provisional Application 60/108,458 filed
on November 12, 1998, the complete disclosure of which is incorporated herein by
reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

10 This invention relates to energetic thermoplastic elastomers which are useful
as binders of high energy compositions, such as propellants, especially rocket
propellants and gun propellants, explosives munitions, gasifiers of vehicle
supplemental restraint systems, or the like, and to methods for synthesizing the same.

2. Description of the Related Art

15 Solid high energy compositions, such as propellants, explosives, gas
generants, and the like comprise solid particulates, such as fuel particulates and/or
oxidizer particulates, dispersed and immobilized throughout a polymeric binder
matrix.

Conventional solid composite propellant binders utilize cross-linked
elastomers in which prepolymers are cross-linked by chemical curing agents. As
20 outlined in detail in U.S. Patent No. 4,361,526, there are important disadvantages to
using cross-linked elastomers as binders. Cross-linked elastomers must be cast within
a short period of time after addition of the curative, which time period is known as the
"pot life". Disposal of a cast, cross-linked propellant composition is difficult, and
usually is accomplished by burning, which poses environmental problems.
25 Furthermore, current state-of-the-art propellant compositions have serious problems
that include their use of nonenergetic binders which have lower performance and high
end-of-mix viscosities.

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In view of the inherent disadvantages associated with the use of cross-linked elastomeric polymers as binder materials, there has been considerable interest in developing thermoplastic elastomers suitable as binders for solid, high energy compositions. However, many thermoplastic elastomers fail to meet important requirements expected of propellant formulations, particularly the requirement of being processible below about 120°C, it being desirable that a thermoplastic elastomeric polymer for use as a binder in a high energy system have a melting temperature of between about 60°C and about 120°C. The melting temperature is desirably at least about 60°C because the propellant composition may be subject to somewhat elevated temperatures during storage and transport, and significant softening of the propellant composition at such elevated temperatures is unwanted. The setting of the melting temperature at not more than 120°C is determined by the instability, at elevated temperatures, of many components which ordinarily go into propellant compositions, particularly oxidizer particulates and energetic plasticizers. Many thermoplastic elastomers exhibit high melt viscosities which preclude high solids loading and many show considerable creep and/or shrinkage after processing. Crosslinkable thermoplastic elastomers typically obtain their thermoplastic properties from segments that form glassy domains which may contribute to physical properties adverse to their use as binders. Thermoplastic elastomers are block copolymers with the property of forming physical cross-links at predetermined temperatures. One thermoplastic elastomer, e.g., Kraton, brand TPE, obtains this property by having the glass transition point of one component block above room temperature. At temperatures below 109°C, the glassy blocks of Kraton form glassy domains and thus physically cross-link the amorphous segments. The strength of these elastomers depends upon the degree of phase separation. Thus, it remains desirable to have controlled, but significant, immiscibility between the two types of blocks, which is a function of their chemical structure and molecular weight. On the other hand, as the

blocks become more immiscible, the melt viscosity increases, thus having a deleterious effect on the processibility of the material.

Above-mentioned U.S. Patent No. 4,361,526 proposes a thermoplastic elastomeric binder which is a block copolymer of a diene and styrene, the styrene blocks providing a meltable crystal structure and the diene blocks imparting rubbery or elastomeric properties to the copolymer. The '526 patent states that this polymer is processed in a volatile organic solvent. Solvent processing is undesirable inasmuch as the dissolved composition cannot be cast in a conventional manner, e.g., into a rocket motor casing. Furthermore, solvent-based processing presents problems with respect to removal and recovery of solvent.

The preparation of energetic thermoplastic elastomers prepared from polyoxetane block copolymers has been proposed in U.S. Patent No. 4,483,978 to Manser and U.S. Patent No. 4,806,613 to Wardle ("the '613 patent"), the complete disclosures of which are incorporated herein by reference to the extent that these disclosures are compatible with this invention. According to the latter, these materials overcome the disadvantages associated with conventional cross-linked elastomers such as limited pot-life, high end-of-mix viscosity, and scrap disposal problems.

The thermoplastic materials proposed by the '613 patent involve elastomers having both (A) and (B) blocks, each derived from cyclic ethers, such as oxetane and oxetane derivatives and tetrahydrofuran (THF) and tetrahydrofuran derivatives. The monomer or combination of monomers of the (A) blocks are selected for providing a crystalline structure at usual ambient temperatures, such as below about 60°C, whereas the monomer or combination of monomers of the (B) blocks are selected to ensure an amorphous structure at usual ambient temperatures, such as above about -20°C. Typical of these materials is the random block copolymer (poly(3-azidomethyl-3-methyloxetane)-poly(3,3-bis(azidomethyl)oxetane), also known as poly(AMMO/BAMO).

Although the materials described by the '613 patent can be synthesized to exhibit acceptable mechanical properties for use as binders in explosive and propellant formulations, they have somewhat low densities. For example, poly(AMMO/BAMO) has a density of around 1.2 g/ml, with the precise value depending upon the proportions of A/B blocks. Additionally, the materials described by the '613 patent also have lower oxygen balance and energetic performance than other thermoset and thermoplastic energetic materials. The less than desirable oxygen balance and energy density of the thermoplastic elastomers disclosed by the '613 patent is a consequence of the use of polymer segments rich in unsymmetrical poly(3,3-disubstituted oxetane) or non-energetic polyether as the softer B block. The B block typically constitutes approximately 65-85% by weight of the thermoplastic elastomer.

It would therefore be a significant advancement in the art to provide energetic thermoplastic elastomer binders that are solid at room temperature and exhibit the excellent mechanical properties of the materials disclosed in the '613 patent, while possessing higher densities and improved oxygen balance and energetic performance.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to provide a thermoplastic elastomer that addresses the aforementioned problems associated with the related art and realizes the advancement expressed above.

In accordance with the principles of this invention, these and other objects are attained by the provision of an energetic thermoplastic elastomer binder that is in a solid state at room temperature and has A blocks and B blocks. The A blocks include one or more polyether(s) derived from monomers of oxetane derivatives and crystalline at temperatures below about 60°C. The B blocks include one or more polyether(s) derived from monomers of oxirane and its derivatives and amorphous at

temperatures above about -20°C. The polyoxetane blocks A and polyoxirane blocks B may be linked by end-capping with diisocyanates and linking the end-capped blocks with difunctional linking chemicals in which each of the two terminal functional groups are reactive with an isocyanate moiety of the diisocyanate.

5 It is also an object of this invention to provide a method for the preparation of the above-described energetic thermoplastic binder of this invention. In accordance with the principles of this invention, this and other objects are achieved by a method in which hydroxyl-terminated polyoxetane A blocks which are crystalline at
10 are amorphous at temperatures above about -20°C are end-capped with a diisocyanate. The diisocyanate preferably has one isocyanate moiety which is more reactive, preferably at least about five times as reactive, with the terminal hydroxyl group of each of the blocks than the other isocyanate moiety, whereby the more reactive isocyanate moiety tends to react with the terminal-hydroxyl groups of the blocks,
15 leaving the less reactive isocyanate moiety free and unreactive. The end-capped A blocks and the end-capped B blocks are mixed together at approximately the stoichiometric ratios that the blocks are intended to be present in the energetic thermoplastic elastomer. The mixture is reacted with a linking compound having two isocyanate-reactive groups which are sufficiently unhindered to react with the free
20 and unreacted isocyanate groups of the end-capped blocks. In this manner, the end-capped blocks are linked, but not crosslinked, to form a thermoplastic elastomer.

 It is still a further object of this invention to provide propellants, especially rocket propellants and gun propellants, explosives, gas generants, or the like containing the above-discussed energetic thermoplastic elastomer binder or made by
25 procedures including the above-discussed method.

 These and other objects, features, and advantages of the present invention will become apparent from the accompanying drawings and following detailed description

which illustrate and explain, by way of example, the principles of the present invention.

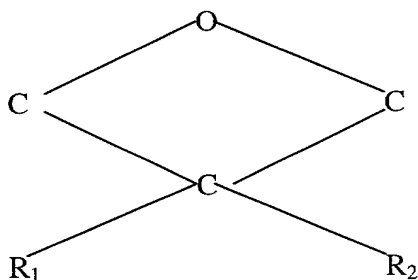
BRIEF DESCRIPTION OF THE DRAWINGS

5 The accompanying drawings are provided to facilitate an understanding of the principles of this invention. In such drawings, FIGS. 1 and 2 are graphs showing the properties of a thermoplastic elastomer prepared in accordance with an embodiment of this invention.

DETAILED DESCRIPTION OF THE INVENTION

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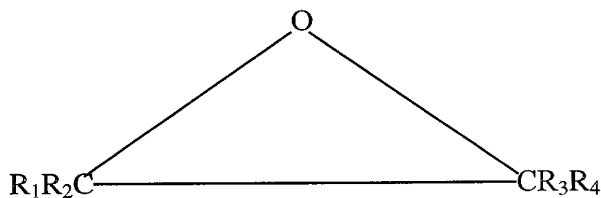
10 The thermoplastic elastomer (AB)_n polymers of this invention include A blocks which are crystalline at temperatures below about 60°C, preferably at temperatures below about 75°C, and B blocks which are amorphous at temperatures down to about -20°C. Each of the A and B blocks are polyethers derived from cyclic ethers. More specifically, the A blocks are derived from monomers of oxetane derivatives. The B blocks are derived from oxirane monomers and their derivatives, 15 preferably energetic oxirane derivatives. The polymers melt at temperatures between about 60°C and about 120°C, and more preferably between about 75°C and about 100°C. The A and B blocks are mutually miscible in the melt. Consequently, the melt viscosity of the block copolymer decreases rapidly as the temperature is raised above the melting point, whereby high energy formulations may include high solids 20 content, e.g., up to about 95% by weight of solid particulates, and can be easily processed. The invention also includes other thermoplastic elastomer block structures, such as ABA tri-block polymers and A_nB star polymers. Contributing to the miscibility of the A and B blocks is their similar chemical structure. Oxetane monomer units used in forming the A blocks of the present invention are generally 25 symmetrically-substituted oxetanes having the general formula:



5 wherein the R_1 and R_2 groups are preferably the same and are selected from moieties having the general formula: $-(CH_2)_nX$, where n is 0-10 and X is selected from the group consisting of $-H$, $-NO_2$, $-CN$, $-Cl$, $-F$, $-O$ -alkyl, $-OH$, $-I$, $-ONO_2$, $-N(NO_2)$ -alkyl, $-C\equiv CH$, $-Br$, $-CH=CH(H \text{ or alkyl})$, $-CO_2$ -(H or alkyl), $-N(H \text{ or alkyl})_2$, $-O-(CH_2)_{1-5}-O-(CH_2)_{0-8}-CH_3$, and N_3 .

10 Examples of oxetane derivatives that may be used in forming the A blocks in accordance with this invention are generally symmetrically-substituted oxetanes including, but are not limited to, the following: BEMO (3,3-bis(ethoxymethyl)oxetane), BCMO (3,3-bis(chloromethyl)oxetane), BMMO (3,3-bis(methoxymethyl)oxetane), BFMO (3,3-bis(fluoromethyl)oxetane), BAOMO (3,3-bis(acetoxymethyl)oxetane), BHMO (3,3-bis(hydroxymethyl)oxetane), BMEMO (3,3-bis(methoxyethoxymethyl)oxetane), BIMO (3,3-bis(iodomethyl)oxetane), BNMO (3,3-bis(nitratomethyl)oxetane), BMNAMO (3,3-bis(methylnitraminomethyl)oxetane), and BAMO (3,3-bis(azidomethyl)oxetane).

20 Oxirane monomer units used in forming the blocks of the present invention have the general formula:



wherein R₁ and R₃ are independently selected from hydrogen and methyl, and R₂ and R₄ are independently selected from hydrogen, alkyl containing from 1 to 10 carbon atoms, chloroalkyl and bromoalkyl containing 1 to 2 carbon atoms, and nitratoalkyl, nitratoalkoxyalkyl, nitroalkyl, nitroalkoxyalkyl, azidoalkyl, azidoalkoxyalkyl, fluoronitroalkyl, and fluoronitroalkoxyalkyl containing 1 to 5 carbon atoms provided that at least one of R₁ to R₄ is not hydrogen.

Examples of energetic oxiranes that may be used in forming the B blocks in accordance with this invention include, but are not limited to glycidyl azide polymers (C₃H₅N₃O) (GAP), especially difunctional GAP, and poly(glycidyl nitrate) (C₃H₅NO₄) (PGN). These polymers have a glass transition temperature below about -20°C and are amorphous at temperatures above -20°C.

Forming thermoplastic elastomers in accordance with the invention involves (1) formation of at least one polyoxetane-derived homopolymer, copolymer, or terpolymer serving as the A blocks and crystalline in nature with a relatively elevated melting point, i.e., between about 60°C and about 120°C, preferably near 80°C and (2) formation of at least one polyoxirane-derived homopolymer, copolymer, or terpolymer serving as the B blocks and amorphous in structure with a glass transition temperature (T_g) below about -20°C.

The selection of the A block may be made based on the properties desired for the intended application of the thermoplastic elastomer. Examples of preferred crystalline A blocks include blocks possessing high energy density, such as those formed from BAMO and/or BMNAMO monomers. Melting temperature and ether oxygen content are additional factors that may be taken into consideration in selecting the monomers.

The properties of the block polymer depends upon the molecular weights of the individual blocks. Typically the A blocks have number average molecular

weights ranging from about 3000 to about 8000, whereas the B blocks have number average molecular weights ranging from about 3000 to about 15,000. The weight ratio of A blocks to B blocks is preferably between about 15:85 to about 40:60. The preferred sizes of the A and B blocks for any particular binder application may be empirically determined.

The thermoplastic elastomers of this invention preferably are in a solid state at room temperature, have a weight average molecular weight of at least 40,000, more preferably at least 60,000, still more preferably at least 80,000, and a number average molecular weight of at least 10,000, more preferably at least 12,000, still more preferably at least 15,000.

Thermoplastic elastomers produced in accordance with the present invention may be admixed with other components of a high energy formulation, such as a propellant formulation. The binder system, in addition to the thermoplastic elastomers, may optionally contain one or more plasticizers for improving the resistance of the thermoplastic elastomer to hardening at low temperatures, which may be included at a plasticizer-to-thermoplastic elastomer weight ratio of up to about 1:1. Suitable high energy plasticizers include glycidyl azide polymer (GAP), nitroglycerine, butanetriol trinitrate (BTTN), alkyl nitratomethyl nitramines, trimethylolethane trinitrate (TMETN), diethylene glycol dinitrate, triethylene glycol dinitrate (TEGDN), bis(dinitropropylacetal/-bis(dinitropropyl)formal (BDNPA/F), and mixtures thereof. Inert plasticizers can also be used. Representative inert plasticizers include, by way of example, dioctyladipate (DOA), isodecylperlargonate (IDP), dioctylphthalate (DOP), dioctylmaleate (DOM), dibutylphthalate (DBP), oleyl nitrile, triacetin, and combinations thereof. The binder system may also contain a minor amount of a wetting agent or lubricant that enables higher solids loading.

The solids content of the high energy composition generally ranges from about 50 wt% to about 95 wt%, higher solids loading generally being preferred so long as

The thermoplastic elastomer may be mixed with the solids and other components of high energy formulation at temperatures above its melting temperature. Blending may be done in conventional mixing apparatus. Because of the low viscosities of the molten polymer, no solvents are required for blending or other processing, such as extrusion.

An important advantage of having a binder which is meltable is that the elastomer from an outdated device containing can be melted down and reused. At the time of such remelting, the binder might be reformulated, e.g., by addition of additional fuel or oxidizer particulates. Accordingly, the thermoplastic elastomer provides for its eventual recycle, as opposed to the burning required for disposal of cross-linked compositions. Because the "pot life" of the thermoplastic propellant exceeds that which would reasonably be required of a propellant or explosive formulation, if any problems develop during casting, the process can be delayed as

The crystalline polyoxetane A blocks and amorphous polyoxirane B blocks, i.e., the respective prepolymers, are each end-capped together or separately with one or more diisocyanates. The end-capped A and B blocks are mixed together and joined by a linking compound which has a pair of isocyanate-reactive functions that are
5 sufficiently unhindered to allow them to react with the free isocyanate moieties of the end-capped copolymers and thereby join the blocks together.

Oxetane and oxirane polymer blocks normally have terminal isocyanate-reactive (e.g., hydroxyl) functions which are end-capped with the diisocyanates in accordance with the invention. Preferably, a first of the isocyanate moieties of the
10 end-capping compound is substantially more reactive with the terminal-hydroxyl moieties of the polymer blocks than the other (second) isocyanate moiety. One of the problems with linking these types of polymer blocks is that substituted oxetane-derived hydroxyl end groups units have neopentyl structures, whereby the terminal primary hydroxyl moieties are substantially hindered and therefore less reactive. The
15 blocks derived from oxirane derivatives are secondary alcohols, making their hydroxyl groups less reactive than the primary hydroxyl group of the oxetane-derived A-block. The diisocyanate preferably is selected so that the first of the isocyanate moieties is capable of reacting with a hydroxyl-group of the polymer blocks while the second isocyanate moiety remains free and unreacted. Diisocyanates are preferably
20 used because isocyanates of higher functionality would result in undesirable levels of cross-linking. The different reactivities of the isocyanate moieties is desirable to ensure that substantial chain extension through linking of like blocks does not occur. Thus, for purposes of this invention, one isocyanate moiety of the diisocyanate should preferably be approximately five times more reactive with terminal hydroxyl groups
25 of oxetane and oxirane blocks than the other group. Preferably one isocyanate moiety is at least about ten times more reactive than the other.

One diisocyanate which is especially useful for purposes of the invention is 2,4-toluene diisocyanate (TDI) in which the isocyanate moiety in the 4-position is

substantially more reactive with hindered terminal hydroxyl moieties than the isocyanate moiety in the 2-position. Isophorone diisocyanate (IPDI) is suitable for some applications, though less so than TDI. Examples of diisocyanates which have not worked well include diphenylmethylene diisocyanate (MDI) and hexamethylene diisocyanate (HDI).

In the end-capping reaction, the diisocyanate is used at an approximately stoichiometric molar amount relative to terminal hydroxyl groups on the polymer chain. Thus, if the polymer chain has a pair of terminal hydroxyl groups, approximately two molar equivalents, e.g., 1.75-2.2 molar equivalents of diisocyanate are used. In the ideal reaction, all of the more reactive isocyanate moieties would react with terminal hydroxyl groups, leaving all of the less reactive isocyanate moieties free. Practically, not all of the diisocyanate reacts in this manner, and some chain extension does occur. Thus, the end-capping reaction may be maximized for particular polymer chains by some adjustment in the relative molar ratios of polymer block and diisocyanate.

In one variant embodiment, the A blocks and B blocks are reacted separately with the diisocyanate, so that there is no competition of the blocks for diisocyanate molecules and each separate end-capping reaction may be carried to substantial completion. The diisocyanate may react more rapidly with one block than the other, but this difference can be compensated for by a longer reaction time with the slower reacting block. The reactivity of the terminal hydroxyl groups varies according to steric factors and also according to side-chain moieties. Energetic oxetanes, for example, generally have side-chain moieties that are electron-withdrawing, making their terminal hydroxyl groups less reactive. Once end-capped with diisocyanate, the reactivities of the polymers for linking purposes is essentially dependent only upon the reactivity of the free isocyanate, not on the chemical makeup of the polymer chain itself. Thus end-capped (A) blocks are substantially as reactive as end-capped (B) blocks. The end-capping of the oxirane blocks in this manner overcomes the

problems associated with linking of oxirane derivative blocks, which have secondary hydroxyl groups.

The end-capping reaction and linking reaction are carried out in a suitable solvent, e.g., one which dissolves the polymer and does not react with the free isocyanate moieties. In a preferred embodiment, the solvent is non-halogenated. Although insubstantial amounts of halogenated solvent may be present, the solution is preferably completely free of any halogenated solvent. The non-halogenated solvent should not react in the urethane reaction (i.e., do not interfere with the end capping catalyst, such as dibutyl tin dilaurate, or the linking catalyst) and forms an azeotrope with water. The solvent or solvents selected preferably are capable of dissolving more than 25% by weight of the blocks (based on total weight of the solvents and blocks) into solution, more preferably at least 35% by weight into solution, and still more preferably 50% by weight into solution. Representative solvents include cyclic ethers such as tetrahydrofuran (THF) and 1,4-dioxane; non-cyclic ethers such as ethylene glycol dimethyl ether; ketones such as methyl ethyl ketone (MEK); and esters such as ethyl acetate. Of these, THF is preferred because of its excellent solubility characteristics.

In a preferred embodiment, the solvent forms an azeotrope with water. In this preferred embodiment, after the blocks are dissolved in excess non-halogenated solvent, the solution may be dried by azeotropic distillation of the solvent, and optionally further concentrated, e.g., via distillation, in the solution to increase the volumetric loading and reaction rate. The blocks then may be end-capped, separately or together, and linked in the same or a different non-halogenated solvent. By distilling off excess solvent to remove water, subsequent reaction with a diisocyanate may proceed without significant interference from competing reactions between the isocyanate moieties and water. Additionally, the solution remains homogeneous and further distillation serves to concentrate the polymer solution, producing higher reaction rates and requiring less reactor capacity. The reaction rates may be improved

by conducting the end-capping reaction at elevated temperatures, such as 30°C to 80°C, more preferably 40°C to 60°C. The process may be conducted by a batch or continuous method. For example, the prepolymer and catalyst may be continuously fed through a mixer/extruder into which is injected a diisocyanate and a diol at appropriate feed rates so that urethane linking occurs within the extruder and energetic thermoplastic elastomer is continuously produced for processing.

Suitable catalysts for promoting the end-capping reaction include, as a preferred class, organic tin compounds with at least one and preferably two labile groups, such as chloride or acetate, bound directly to the tin. Suitable tin catalyst include diphenyl tin dichloride, dibutyl tin dichloride, dibutyl tin dilaurate, dibutyl tin diacetate. Tertiary amine catalysts may also be used.

The linking compound is one which has two functional groups which are sufficiently reactive and unhindered to react with the free isocyanate moieties on the end-capped blocks so as to link A blocks to B blocks, A blocks to A blocks, and B blocks to B blocks in a urethane reaction. Preferred functional groups are hydroxyl groups, although amine, amide, and carboxyl groups, and mixtures thereof also react in a urethane reaction. Primary functional groups are preferred. The linking compound may be a short, straight carbon chain having terminal hydroxyl groups, e.g., 1,4-butanediol, 1,3-propanediol, ethylene glycol, and 1,6-hexanediol.

Alternatively, the linking compound may be an oligomer, especially a urethane oligomer, having two functional groups which are sufficiently unhindered to react with the free isocyanate moieties on the end-capped blocks so as to link A blocks to B blocks, A blocks to A blocks, and B blocks to B blocks in a urethane reaction. Preferred functional groups of the oligomer are hydroxyl groups, although amine, amide, and carboxyl groups, and mixtures thereof also react in a urethane reaction. Primary functional groups are preferred.

It is to be appreciated that a wide variety of difunctional compounds could be used for linking the end-capped blocks.

As in the end-capping reaction, some solvent is preferably used, as is a catalyst, such as described above. Conveniently, the reaction mixtures of the A blocks and B blocks may be mixed together without prior separation of the blocks from their respective end-capping reaction mixtures. The linking compound can be

added directly to this mixture of A and B blocks. The catalyst is thereby already present when the linking compound is added.

The linking compound is added in an amount such that the total number of linking-compound functional groups approximately equals the total number of free isocyanate groups of the end-capped polymer blocks. Thus, to provide an (AB)_n polymer with multiple blocks in each chain, the linking compound to polymer block molar ratio is in the range of 0.9-1.1, e.g., 1.0. Accordingly, optimal molar ratios of blocks and linking chemicals may have to be empirically determined.

In the end-capping and block linking steps, the reaction can be followed with NMR and IR. With NMR, the urethane-forming reaction can be followed through the methylene groups on the polymer adjacent to the terminal hydroxyl groups. With IR, the change from isocyanate to urethane can be directly followed.

Synthesis of polyoxetanes is described in U.S. Patent Nos. 4,483,978 and 4,806,613, the complete disclosures of which are incorporated herein by reference to the extent such disclosures are compatible with this invention.

The invention will now be described in greater detail by way of the following examples, which are not to be construed as being exhaustive as to the scope of this invention.

As referred to herein, "dry" means that less than 1 wt% water was present.

For the following experiments, poly(azidomethyloxirane) was supplied by 3M Speciality Chemicals of St. Paul, MN (Lot L-12564). Unless otherwise specified, all other materials were obtained from Aldrich of Milwaukee, WI.

EXAMPLE 1 (poly(3,3-bis(azidomethyl)oxetane))

A 5 liter jacketed flask equipped with a mechanical stirrer was charged with 600 grams of tribromoneopentylalcohol (AmeriBrom, Inc. of New York), 1200 ml of

toluene, and 6 grams of tetrabutylammonium bromide. The mixture was cooled to 12°C and 193 grams of sodium hydroxide was added dropwise as a 40 wt% solution keeping the temperature at 12°C. After 36 hours the reaction mixture was washed with water until the pH was less than 9 to obtain the crude product which was distilled to obtain 3,3-bis(bromomethyl)oxetane in 65% yield.

A 5 liter jacketed flask equipped with a mechanical stirrer was charged with 1450 grams of the 3,3-bis(bromomethyl)oxetane and 1720 ml of toluene. The mixture was stirred and heated to 60°C before 1600 ml of water, 14.7 grams of tetrabutylammonium bromide, and 862 grams of sodium azide were added. After 24 hours, the reaction mixture was cooled to room temperature and washed three times with 2000 ml of water. The toluene and water were removed from the organic layer by distillation to give pure 3,3-bis(azidomethyl)oxetane in 85% yield.

Under an argon atmosphere, 14.94 grams of butane diol was added to a flame dried 5 liter round-bottomed flask charged with 1340 ml of dry methylene chloride. To this mixture, 11.77 grams of borontrifluoride-etherate was added and the reaction was allowed to proceed for one hour at room temperature. The reactor was then cooled to -10°C and 937.78 grams of the 3,3-bis(azidomethyl)oxetane was added. The solution was allowed to come to room temperature and left to react for three days. The reaction was then quenched by the addition of 50 ml of saturated brine solution. The organic phase was separated off and washed with 100 ml of 10 wt% sodium bicarbonate solution before the solvent was removed on a rotovapor. The resulting liquid was then poured into 5 liters of methanol to precipitate the polymer, which was filtered from the solution and dried under vacuum at 30°C.

EXAMPLE 2 (poly(3-azidomethyl-3-methyloxetane))

A 5 liter jacketed flask equipped with a mechanical stirrer was charged with 1062 grams of sodium azide, 1972 ml of water, and 2450 grams of 3-bromomethyl-3-methyloxetane (supplied by AmeriBrom, Inc. of New York). This mixture was

brought to reflux with vigorous mixing. After 48 hours the mixture was cooled to room temperature. The organic layer was separated off and washed three times with 1000 ml of water before being dried over molecular sieves to yield pure 3-azidomethyl-3-methyloxetane in 85% yield.

- 5 Under an argon atmosphere, 14.94 grams of butane diol was added to a flame dried 5 liter round-bottomed flask charged with 1.340 ml of dry methylene chloride. To this mixture, 11.77 grams of borontrifluoride-etherate was added and the reaction was allowed to proceed for one hour at room temperature. The reactor was then cooled to -10°C and 937.78 grams of the 3-azidomethyl-3-methyloxetane was added.
- 10 The solution was allowed to come to room temperature and left to react for three days. The reaction was then quenched by the addition of 50 ml of saturated brine solution. The organic phase was separated off and washed with 100 ml of 10 wt% sodium bicarbonate solution before the solvent was removed on a rotovapor. The resulting liquid was then poured into 5 liters of methanol to precipitate the polymer, which was
- 15 filtered from the solution and dried under vacuum at 30°C.

EXAMPLE 3 (Random block copolymer of poly(azidomethyloxirane) and poly(3,3-bis(azidomethyl)oxetane))

- In a 250 ml round bottom flask, 19.62 grams of dry difunctional poly(azidomethyloxirane) with a hydroxyl equivalent weight of 1269 and 6.63 grams
- 20 of dry poly(3,3-bis(azidomethyl)oxetane) with a hydroxyl equivalent weight of 3017 were dissolved in 80 ml of dry methylene chloride. The solution was concentrated by evaporation of the methylene chloride via a rotovapor until the solution became cloudy. To this solution, 0.12 ml of dibutyltin dilaurate and 3.11 grams of toluene-2,4-diisocyanate were added while stirring with a magnetic-driven stirrer at ambient
- 25 temperature and pressure. After four hours, 0.805 grams of butane-1,4-diol was added, causing the solution to become steadily more viscous. After another 18 hours, the solution was too viscous to stir with the magnetic-driven stirrer and it was diluted with 50 ml of methylene chloride before being poured into methanol in a volume ratio

of 1:5. The methanol was decanted off, and the precipitated polymer was washed three times with fresh methanol (1:5 volume ratio) to give a rubbery granular product with the following properties:

$M_n = 28440$

5 $M_w = 219500$

$M_w/M_n = 7.7$

$E^{1.0} \text{ (psi)} = 511$

$\epsilon_m \text{ (\%)} = 251$

$\epsilon_f \text{ (failure) (\%)} = 269$

10 $\sigma_m \text{ (psi)} = 194$

$\sigma_m \text{ (corrected) (psi)} = 702$

ShoreA = 52

Density = 1.31 g/cm^3

($E^{1.0}$ represents Young's Modulus. ϵ_m and ϵ_f , respectively representing
15 maximum measured strain and calculated failure strain, and σ_m and σ_m (corrected),
respectively representing measured maximum stress and calculated corrected
maximum stress, were measured using an INSTRON model 1225. The crosshead
speed was 0.6 inches per minute. Measurements were made at room temperature
using 20 mm x 4 mm dumbbell samples. ShoreA representing hardness was measured
20 on a Shore Conveloader at room temperature.)

EXAMPLE 4 (Random block copolymer of poly(nitratomethyloxirane) and poly(3,3-bis(azidomethyl)oxetane))

In a 100 ml round bottom flask, a dried solution of 22.69 grams of difunctional
poly(nitratomethyloxirane) (supplied by Thiokol of Elkton, Md., now Cordant
25 Technologies Inc.) with a hydroxyl equivalent weight of 1285 and 9.73 grams of
poly(3,3-bis(azidomethyl)oxetane) with a hydroxyl equivalent weight of 3017 was
dissolved in 45 ml of dry methylene chloride. The solution was concentrated by
evaporation of the methylene chloride via a rotovapor until the solution became

cloudy. To this solution, 0.152 ml of dibutyltin dilaurate and 3.637 grams of toluene-2,4-diisocyanate were added and stirred with a magnetic-driven stirrer at ambient temperature and pressure. After three days, 0.941 grams of butane-1,4-diol was added, causing the solution to become steadily more viscous. After one more day, the solution was too viscous to stir with the magnetic-driven stirrer, and was diluted with 30 ml of methylene chloride and 4 ml of methanol before being poured into methanol in a volume ratio of 1:5. The methanol was decanted off, and the precipitated polymer was washed three times with fresh methanol (1:5 volume ratio) to give a rubbery granular product with the following properties:

- 10 Mn = 15020
- Mw = 105900
- Mw/Mn = 7.1
- $E^{1.0}$ (psi) = 581
- ϵ_m (%) = 325
- 15 ϵ_f (failure) (%) = 358
- σ_m (psi) = 182
- σ_m (corrected) (psi) = 806
- ShoreA = 58
- Density = 1.42 g/cm³

20 EXAMPLE 5 (Random block copolymer of poly(azidomethyloxirane) and poly(3,3-bis(azidomethyl)oxetane))

- In a 250 ml round bottom flask, a dry solution of 15.0 grams of difunctional poly(azidomethyloxirane) with a hydroxyl equivalent weight of 1174 and 5.0 grams of poly(3,3-bis(azidomethyl)oxetane) with a hydroxyl equivalent weight of 1626 was dissolved in 60 ml of tetrahydrofuran. The solution was concentrated by evaporation of the tetrahydrofuran via a rotovapor until 6.6 grams of solvent remained. To this solution, 1 ml of dibutyltin dilaurate was added and the solution was warmed to 50°C. The solution was stirred with a magnetic-driven stirrer and 2.76 grams of toluene-2,4-

diisocyanate were added. After four minutes, 0.714 grams of butane-1,4-diol was added, causing the solution to become more viscous rapidly. After another 2 minutes, the solution was quenched by adding a solution of 2 ml of methanol in 30 ml of tetrahydrofuran. This solution was then poured into methanol in a volume ratio of 1:5. The methanol was decanted off, and the precipitated polymer was washed three times with fresh methanol (1:5 volume ratio) to give a rubbery granular product with the following properties:

$$M_n = 21420$$

$$M_w = 298500$$

$$M_w/M_n = 14$$

$$E^{1.0} (\text{psi}) = 271$$

$$\epsilon_m (\%) = 161$$

$$\epsilon_f (\text{failure}) (\%) = 178$$

$$\sigma_m (\text{psi}) = 100$$

$$\sigma_m (\text{corrected}) (\text{psi}) = 256$$

$$\text{ShoreA} = 41$$

EXAMPLE 6 (Random block copolymer of poly(azidomethyloxirane) and poly(3,3-bis(azidomethyl)oxetane))

In a 25 ml round bottom flask, a urethane oligomer was prepared by dissolving 1.55 grams of toluene-2,4-diisocyanate in 4 ml tetrahydrofuran and adding to the solution 0.1 ml of dibutyltin dilaurate followed by 1.60 grams of butane-1,4-diol.

In a separate 250 ml round bottom flask, 17.94 grams of dry difunctional poly(azidomethyloxirane) with a hydroxyl equivalent weight of 1174 and 6.63 grams of dry poly(3,3-bis(azidomethyl)oxetane) with a hydroxyl equivalent weight of 2390 were dissolved in 100 ml of tetrahydrofuran. The solution was concentrated and dried by evaporation of the tetrahydrofuran via a rotovapor under reduced pressure until 20 grams of solvent remained. To this solution, 0.75 ml of dibutyltin dilaurate and 3.097 grams of toluene-2,4-diisocyanate were added while stirring with a magnetic-driven

stirrer. After 1 hours, the urethane oligomer was added to this solution, causing it to become steadily more viscous. After 20 minutes, the was too viscous to stir with the magnetic-driven stirrer and it was diluted with 20 ml of dry tetrahydrofuran, and then allowed to react for a further 20 minutes before being poured into methanol in a volume ratio of 1:5. The precipitated polymer was washed three times with fresh methanol (1:5 volume ratio) to give a rubbery granular product with the properties shown in FIGS. 1 and 2 and set forth below:

Mn = 26240

Mw = 175500

10 Mw/Mn = 6.69

Molecular weight distribution was determined by gel permeation chromatography using polystyrene standards, with the results shown in FIG. 1. The GPC trace in FIG. 1 demonstrates that the prepolymers were linked to produce a copolymer having a higher molecular weight and dispersivity than the homopolymer blocks. The DMA trace in FIG. 2 shows the melt transition of random block (BAMO-GAP)_n at 75-80°C with a material modulus reducing only slowly before this point.

The foregoing detailed description of the preferred embodiments of the invention has been provided for the purpose of explaining the principles of the invention and its practical application, thereby enabling others skilled in the art to understand the invention for various embodiments and with various modifications as are suited to the particular use contemplated. The foregoing detailed description is not intended to be exhaustive or to limit the invention to the precise embodiments disclosed. Modifications and equivalents will be apparent to practitioners skilled in this art and are encompassed within the spirit and scope of the appended claims.

WHAT IS CLAIMED IS:

1. An energetic thermoplastic elastomer having A blocks and B blocks and being present in a substantially solid state suitable for use as a binder for at least one of a propellant, explosive, and gasifier, the energetic thermoplastic elastomer
5 being formed from a composition comprising, as constituents:

A blocks terminated with isocyanate-reactive groups derived from monomers comprising one or more oxetane derivatives, the A blocks being crystalline at temperatures below about 75°C;

- B blocks terminated with isocyanate-reactive groups derived from monomers
10 comprising at least one member selected from the group consisting of oxirane and derivatives thereof, the B block(s) being amorphous at temperatures above about -20°C; and

linking groups derived from at least one diisocyanate and at least one linking compound comprising two functional groups which are reactive with isocyanate
15 moieties of the diisocyanate.

2. An energetic thermoplastic elastomer as defined in claim 1, wherein:
the diisocyanate contains a first isocyanate moiety which is at least five times more reactive with the terminal groups of the blocks than a second isocyanate moiety thereof, whereby the more reactive first isocyanate moiety is capable of reacting with
20 and end capping the terminal groups of the blocks, leaving the less reactive second isocyanate moiety free and unreacted; and

the linking compound has two isocyanate-reactive groups which are sufficiently sterically unhindered to be reactive with the free and unreacted second isocyanate moieties of the end-capped blocks.

3. An energetic thermoplastic elastomer as defined in claim 2, wherein
25 the diisocyanate comprises toluene diisocyanate.

4. An energetic thermoplastic elastomer as defined in claim 1, wherein the A blocks are crystalline at temperatures below about 60°C.

5. An energetic thermoplastic elastomer as defined in claim 1, wherein the A blocks comprise homopolymers, copolymers, or terpolymers derived from one or more symmetrically-substituted oxetane monomers comprising at least one member selected from the group consisting of 3,3-bis(methylnitraminomethyl)oxetane and 3,3-bis(azidomethyl)oxetane.

6. An energetic thermoplastic elastomer as defined in claim 1, wherein the B block comprises a difunctional glycidyl azide polymer.

7. An energetic thermoplastic elastomer as defined in claim 1, wherein the B block comprises poly(glycidyl nitrate).

8. An energetic thermoplastic elastomer as defined in claim 1, wherein the thermoplastic elastomer has a weight average molecular weight of at least 40,000 and a number average molecular weight of at least 10,000.

9. An energetic thermoplastic elastomer as defined in claim 1, wherein the thermoplastic elastomer has a weight average molecular weight of at least 60,000 and a number average molecular weight of at least 12,000.

10. An energetic thermoplastic elastomer as defined in claim 1, wherein the thermoplastic elastomer has a weight average molecular weight of at least 80,000 and a number average molecular weight of at least 15,000.

11. An energetic thermoplastic elastomer as defined in claim 1, wherein a weight ratio of A to B blocks is between about 15:85 to about 40:60.

12. An energetic thermoplastic elastomer as defined in claim 1, wherein the isocyanate-reactive terminal groups of the A and B blocks are hydroxyl groups.

13. An energetic thermoplastic elastomer of claim 1, wherein the isocyanate-reactive terminated groups of the B blocks are secondary hydroxyl groups.

14. A binder comprising:

about 50 wt% to about 95 wt% of at least one solid selected from the group
5 consisting of fuel material particulates and oxidizer particulates; and
at least one energetic thermoplastic elastomer having A blocks and B blocks
and being present in a substantially solid state to immobilize the particulates, the
energetic thermoplastic elastomer being formulated from a composition comprising,
as constituents:

10 A blocks terminated with isocyanate-reactive groups and derived from
monomers comprising one or more oxetane derivatives, the A blocks being crystalline
at temperatures below about 75°C;

B blocks terminated with isocyanate-reactive groups derived from
monomers comprising at least one member selected from the group consisting of
15 oxirane and derivatives thereof, the B blocks being amorphous at temperatures above
about -20°C; and

linking groups derived from at least one diisocyanate and at least one
linking compound.

15. A binder as defined in claim 14, wherein:

20 the diisocyanate contains a first isocyanate moiety which is substantially more
reactive with the terminal groups of the blocks than a second isocyanate moiety
thereof, whereby the more reactive first isocyanate moiety is capable of reacting with
and end capping the terminal groups of the blocks, leaving the less reactive second
isocyanate moiety free and unreacted; and

25 the linking compound has two isocyanate-reactive groups which are
sufficiently sterically unhindered to be reactive with the free and unreacted second
isocyanate moieties of the end-capped blocks.

16. A binder as defined in claim 14, wherein the A blocks are crystalline at temperatures below about 60°C.

17. A binder as defined in claim 14, wherein the A blocks comprise homopolymers, copolymers, or terpolymers derived from one or more symmetrically-substituted oxetane monomers comprising at least one member selected from the group consisting of 3,3-bis(methylnitraminomethyl)oxetane and 3,3-bis(azidomethyl)oxetane.

18. A binder as defined in claim 14, wherein the B block comprises a difunctional glycidyl azide polymer.

19. A binder as defined in claim 14, wherein the B block comprises poly(glycidyl nitrate).

20. A binder as defined in claim 14, wherein the isocyanate-reactive terminated groups of the B blocks are secondary hydroxyl groups.

21. A binder as defined in claim 14, wherein the solid comprises at least one member selected from the group consisting of aluminum, ammonium perchlorate, and ammonium nitrate.

22. A binder as defined in claim 14, further comprising at least one member selected from the group consisting of cyclotetramethylene tetranitramine (HMX), cyclotrimethylene trinitramine (RDX), 2,4,6,8,10,12-hexanitro-2,4,6,8,10,12-hexaazatetracyclo[5.5.0.0^{5,9}.0^{3,11}]-dodecane (CL-20), and 4,10-dinitro-2,6,8,12-tetraoxa-4,10-diazatetracyclo[5.5.0.0^{5,9}.0^{3,11}]-dodecane (TEX).

23. A binder as defined in claim 14, further comprising at least one high energy plasticizer selected from the group consisting of nitroglycerine, butanetriol trinitrate (BTTN), alkyl nitratomethyl nitramines, trimethylolethane trinitrate

(TMETN), diethylene glycol dinitrate, triethylene glycol dinitrate, glycidyl azide polymer (GAP), and bis(dinitropropylacetal/-bis(dinitropropyl)formal (BDNPA/F).

24. A binder as defined in claim 14, wherein the isocyanate-reactive terminal groups of the A and B blocks are hydroxyl groups.

5 25. A rocket motor propellant comprising the binder of claim 14.

26. A gun propellant comprising the binder of claims 14.

27. An explosive comprising the binder of claim 14.

28. A gasifier comprising the binder of claim 14.

29. A method of preparing an energetic thermoplastic elastomer having A
10 blocks which are crystalline at temperatures below about 75°C and the B blocks
which are amorphous at temperatures above about -20°C, the A blocks being
polyethers derived from monomers comprising oxetane derivatives, the B blocks
being polyethers derived from monomers comprising at least one member selected
from the group consisting of oxiranes and derivatives thereof, the method comprising:
15 providing A blocks and B blocks at approximately the stoichiometric ratios
that are intended to be present in the energetic thermoplastic elastomer, the A blocks
being terminated with isocyanate-reactive functional groups, derived from monomers
comprising oxetane derivatives, and crystalline at temperatures below about 75°C, the
B blocks being terminated with isocyanate-reactive functional groups, derived from
20 monomers comprising at least one member selected from the group consisting of
oxiranes and derivatives thereof, and amorphous at temperatures above about -20°C;
end-capping the A blocks and the B blocks by reacting the A blocks and B
blocks with at least one diisocyanate in which a least a first isocyanate moiety thereof
is substantially more reactive with the terminal groups of the blocks than a second
25 isocyanate moiety thereof, whereby the more reactive first isocyanate moiety is

capable of reacting with the terminal groups of the blocks, leaving the less reactive second isocyanate moiety free and unreacted; and

reacting the end-capped A blocks and the end-capped B blocks together with a linking compound having two isocyanate-reactive groups which are sufficiently
5 unhindered to reactive with the free and unreacted second isocyanate moieties of the end-capped polymers.

30. A method as defined in claim 29, wherein the diisocyanate comprises toluene diisocyanate.

31. A method as defined in claim 29, wherein the A blocks are crystalline
10 at temperatures below about 60°C.

32. A method as defined in claim 29, wherein the A blocks are homopolymers, copolymers, or terpolymers derived from one or more symmetrically-substituted oxetane monomers comprising at least one member selected from the group consisting of 3,3-bis(methylnitraminomethyl)oxetane and
15 3,3-bis(azidomethyl)oxetane.

33. A method as defined in claim 29, wherein the B block comprises a difunctional glycidyl azide polymer.

34. A method as defined in claim 29, wherein the B block comprises poly(glycidyl nitrate).

20 35. A method as defined in claim 29, wherein the thermoplastic elastomer has a weight average molecular weight of at least 40,000 and a number average molecular weight of at least 10,000.

36. A method as defined in claim 29, wherein the thermoplastic elastomer has a weight average molecular weight of at least 60,000 and a number average
25 molecular weight of at least 12,000.

37. A method as defined in claim 29, wherein the thermoplastic elastomer has a weight average molecular weight of at least 80,000 and a number average molecular weight of at least 15,000.

38. A method as defined in claim 29, wherein a weight ratio of A to B blocks is between about 15:85 to about 40:60.

39. A method as defined in claim 29, wherein the isocyanate-reactive terminal groups of the A and B blocks are hydroxyl groups.

40. A method as defined in claim 29, wherein the isocyanate-reactive terminated groups of the B blocks are secondary hydroxyl groups.

ABSTRACT OF THE DISCLOSURE

This thermoplastic elastomer is present in a substantially solid state suitable for use as a binder for a propellant, explosive, and/or gas generant of a supplemental restraint system. The thermoplastic elastomer is formed from a composition including

5 A blocks which are crystalline at temperatures below about 75°C and B blocks which are amorphous at temperatures above about -20°C. The A blocks are derived from oxetane derivatives and the B blocks are derived from oxiranes and derivatives thereof. The A blocks and B-blocks are end-capped with a diisocyanate having a first isocyanate moiety that is substantially more reactive with the terminal groups of the

10 blocks than the second isocyanate moiety, whereby the more reactive first isocyanate moiety is capable of reacting with the terminal groups of the blocks, leaving the less reactive second isocyanate moiety free and unreacted. The end-capped A blocks and the end-capped B blocks are linked together with a linking compound having two isocyanate-reactive groups which are sufficiently unhindered to react with the free

15 and unreacted isocyanate moieties of the end-capped polymers.

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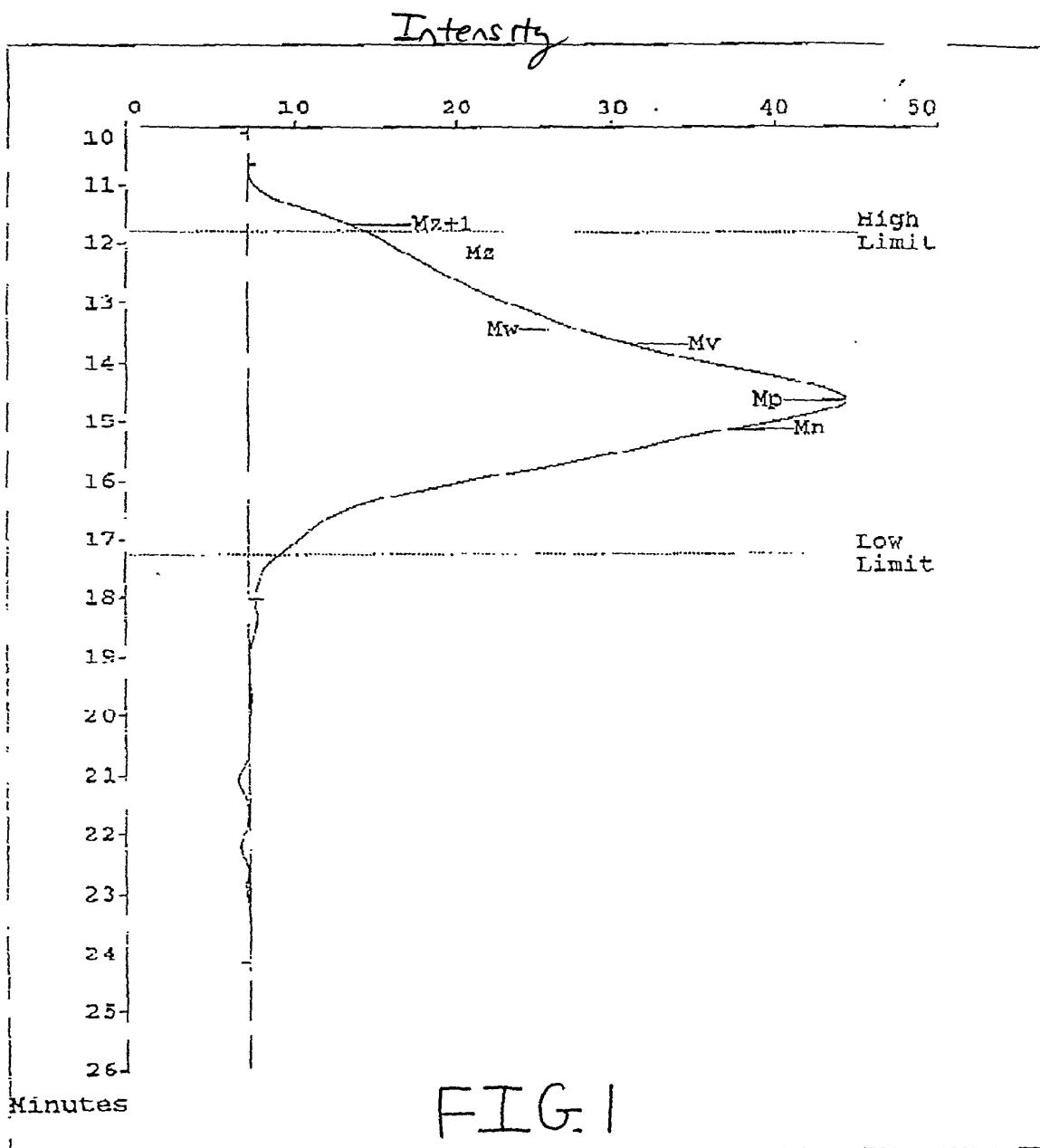


FIG. 2

25% BAMO-GAP : 1561/51 4/15/98

